

Research and Application of Robot Force Control for Friction Stir Welding

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Abstract: In this paper, the composition, principle and method of robot force control for friction stir welding were studied. Based on the RSI interface of robot and C++ language, a host computer and control system for robotic friction stir welding was developed, and on-line monitoring of data, displaying of historical data and preserving of welding- process data were realized. According to the technological characteristics of robotic friction stir welding, the constant force control of welding-process was realized by combining traditional PID control and adaptive control. The results indicated that the secondary developed host computer and control system had the characteristics of simple operation, comprehensive data monitoring, high precision of force control and stable welding process.

1 INTRODUCTION

Friction stir welding (FSW) is a solid state joining technology invented by The Welding Institute in 1991 (LONGHURST, W. R, et.al, 2010). Compared with traditional fusion welding technology, welding defects, such as crack and void can be effectively avoided by FSW. And it has the advantages of high mechanical properties, small deformation, low pollution and low energy consumption. Therefore, FSW is especially suitable for joining aluminum alloys whose melting points relatively low. For FSW, welding force is a key parameter. And the indentation, rotating speed and forward speed of the welding tool will have a significant effects on the welding force (LONGHURST, W, et.al, 2011; MELENDEZ, M, et.al, 2003; MISHRA, R, et.al, 2005; YUSSOF, H, et.al, 2015; ZHAO, X, et.al, 2008). Usually, larger indentation can induce, larger the contact area between welding tool and the base material, as a result, the welding force is larger.

Robotic welding system integrates advanced manufacturing technologies such as precision, flexibility, intellectualization, software application and development. This is especially suitable for welding work-piece with complex three-dimensional surface structure. The welding of complex three-dimensional surface structure is an important-direction for the future development of FSW. In

addition, constant Z-axial force is a key parameter for obtaining stable welding quality. However, due to the limited load capacity and flexibility of the robot, it is difficult to ensure the steady downward force of the welding tool on the work-piece in FSW process. Therefore, it is of great significance to ensure the constant of Z-axial force for improving the quality of robotic FSW.

2 COMPOSITION OF Z-AXIAL FORCE CONTROL SYSTEM

2.1 Composition of Control System

As shown in Figure 1, FSW control system is composed of a six-axis robot and its control system, host computer control system, data acquisition and processing system, force sensor system, spindle motor, stirring needle, frequency conversion control system and Bus control system. Six-axis robot and its control system have high flexibility, high trajectory accuracy, and thus the processing of arbitrary trajectory in space can be realized. It is important for realizing FSW of complex three-dimensional surface structure. The host computer control system is composed of operating interface system and C++ program. The operating interface

system is used to realize functions, such as welding process parameters setting, data calling, welding mode selection, system alarm display, real-time welding data curve display and data storage and conversion. C++ program system is used to communicate with slave system and realize data exchange. The constant force control of welding process was realized by the feedback force of C++ program system collected. Data acquisition and processing system is used to collect and process force sensing values and transmit to PC by OPC. Force sensor system are transformed by converter to measure the Z-axial force value in welding process. Spindle motor is controlled by frequency conversion system to realize speed control in welding process. Bus control system includes Profinet communication between robot and data acquisition system, RSI communication between robot and host computer, OPC communication between data acquisition system and host computer. It realizes data exchange between robot control system, host computer system, data acquisition system and slave system (force sensor, frequency converter, etc.). These data are important guarantee to realize the coordinated operation of the whole system.

2.2 Data Acquisition and Processing System

Accurate acquisition and processing of Z-axial force is an important foundation and guarantee for realizing constant force in FSW process. Data acquisition and processing system includes force acquisition (induction) module, signal amplifier, signal converter module, and AI data acquisition module and data processing software. As shown in Figure 2, the force induction module is used as a sensitive element (mv level induction), which is amplified by a signal amplifier. And then it is converted to the values that can be read by the AI analog module by signal converting module. Finally, the collected values are processed and converted by data software to the actual force values. The data acquisition and processing system regulates sensitive signals, including functions of impedance matching, limiting, zero adjustment correction, isolation, and wave filter (low pass, power frequency and GSM filter). And finally converts them into 4-20 mA signals with strong interference. These signals (4-20 mA signals) are collected and processed by industrial-level PLC analog module. The influence of gravity changes of the self-weight of spindle motor and cable that caused by welding angle change in the welding process are eliminated. As a result, the accuracy and stability of data transmission can be ensured.

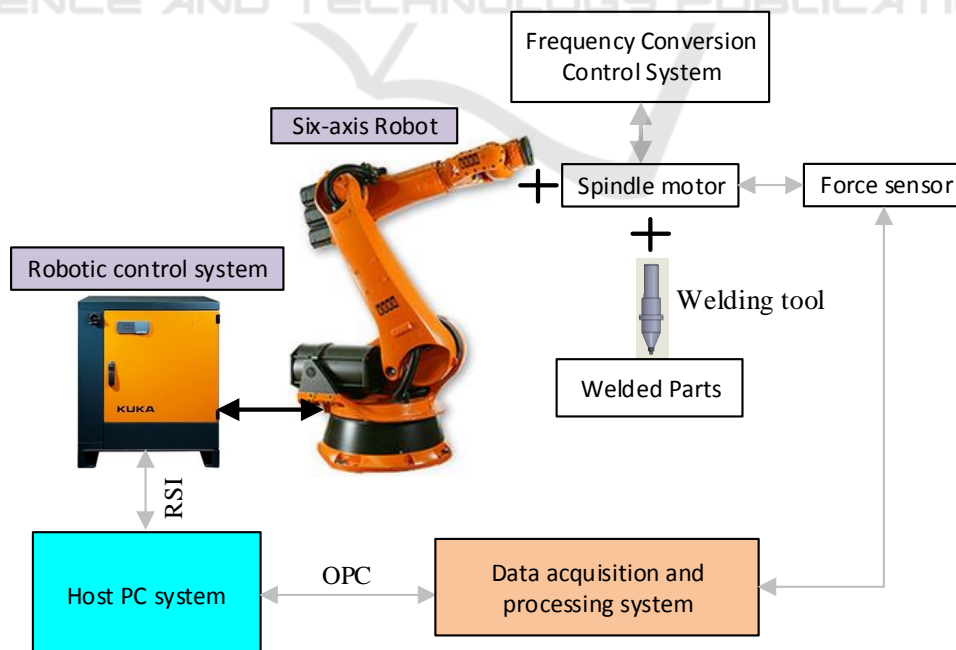


Figure 1. Composition of control system.

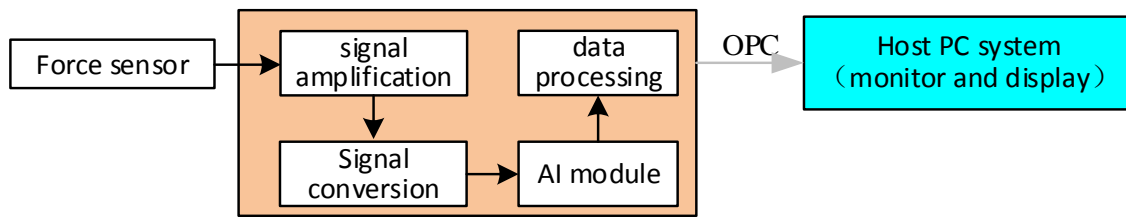


Figure 2. Data Acquisition and Processing.

3 CONTROL METHODS AND PRINCIPLES

3.1 Control Principle of Host PC

The host computer is an important human-computer interface, and it realizes the functions of parameter setting, data calling, mode selection, data monitoring, alarm display and historical data reproduction. Mature interface development software, such as Kingview, Intouch and Labview, has the characteristics of mature, simple development and short process cycle. However, they cannot directly develop robot program further. Therefore, these kinds of software can not directly control the program of the robot and Z-axis force of the robot. Based on C++ powerful development language, robot program will be redeveloped by the KUKA RSI interface. The host computer exchanges data with Siemens PLC through OPC that is simple in communication, strong in reliability and high in stability, so the force value reading can be realized. At the same time, the host computer exchanges data between the robot and the host computer through KUKA RSI interface. The robot program is redeveloped using C++ language, and its functions includes reading the position information of the robot, PID control and other logical control. Closed-loop of Z-axis force control can be realized by the force value that is used as the input and feedback of the parameters.

3.2 Control Method of Z-axis Force

3.2.1 Control Principle of Z-axis Force

Figure 3 is schematic diagram of constant force control. The communication between the robot and the host computer is realized through the KUKA RSI interface, and the robot program is redeveloped using C++ language. In FSW process, after comparing setting value with actual value of Z-axis

force, the redeveloped program tunes and adjusts PID parameters by control algorithm combined with conventional PID and adaptive control, and controls and adjusts robotic attitude in real time. At the same time, considering the timeliness of RSI communication and force feedback, as well as time-delay of robot execution, it is necessary to fine-tune and delay the PID parameters according to the position parameter information of robot feedback, so that the difference between actual value and setting value of Z-axis force can be reduced continuously and Z-axis force can be kept constant within the range of +10% to achieve the purpose of constant force control.

3.2.2 Adaptive Control Algorithm

Traditional PID control is one of the earliest developed control strategies. It is used widely in process control and motion control because of its simple algorithm, strong robustness and high reliability. According to statistics, PID control methods account for more than 90% in industrial control. Traditional PID is also the most used and mature control method in force control. Common application situation of force control includes robot grinding, robot polishing, hydraulic pressure control test bench and force control of robotic FSW. In process of force control of robotic FSW, the welding tool needs to overcome the larger axial resistance because of its direct contact with welded materials. At the same time the value of axial resistance is significantly affected by the amount of force, rotating speed and forward speed of the welding tool. So there are many uncertain factors which can influence the Z-axis force. It is difficult to ensure the system can obtain well welding performance under all working conditions by using conventional PID, even the phenomenon of instability and welding penetration be occur due to the influence of inappropriate parameters.

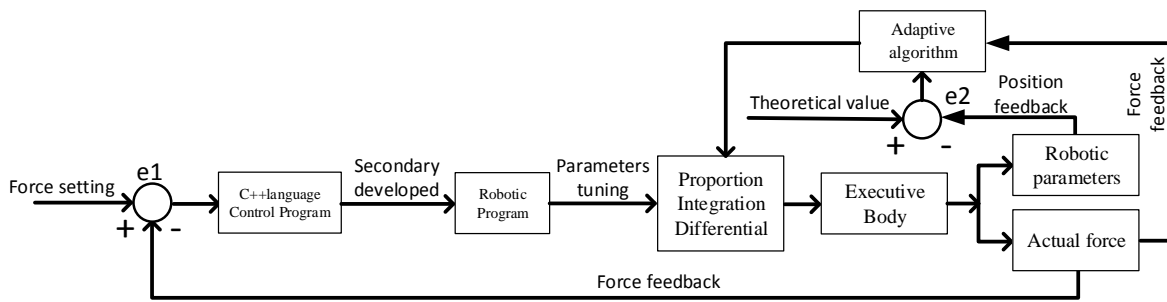


Figure 3. Control principle of Z-axis force.

In view of the shortcomings of the conventional PID control methods, and according to the characteristics of FSW process, a method combining conventional PID control algorithm with adaptive control is adopted. This proposed method not only has the characteristics of high precision, robustness and reliability of the conventional PID control, but also increases the flexibility and adaptability of the system.

The tuning process of parameters of PID algorithm that adding adaptive control algorithm mainly refers to the process of pre-setting parameters and continuous optimization of pre-setting parameters. Firstly, the pre-setting PID parameters K_{P1} (Proportion), K_{I1} (Integration) and K_{D1} (Differential) are determined according to the setting force. Then, in the process of robot welding, according to the difference $e1$ between force feedback and predicted value (Figure 3), the optimized PID parameters $K'P$, $K'I$ and $K'D$ are determined by comparing, reasoning and choosing. The optimized PID parameters of this process is calculated and defined from the parameters that computed by $e1$ and summarized by experience. Finally, according to the $e2$ that is difference between actual position and the ideal position of robot (Figure 3), the final parameters K_P , K_I , K_D are defined by changing the coefficients of the parameters $K'P$, $K'I$ and $K'D$. In this process, the

increase or decrease of the coefficients are mainly based on $e2$ (including positive and negative). The arithmetic is shown in Figure 4.

4 WELDING PROCESS RESEARCH AND APPLICATION RESULT ANALYSIS

In FSW, the stress of the welding tool is large, this causes structural deformation of welding equipment easily and deviation of welding position. Therefore, it is necessary to control the welding process force of Z-axial. The control mode of FSW mainly includes constant displacement and constant force control. The main purpose of constant displacement is to obtain a reasonable displacement. However, due to the sensitive force change in welding process, a small change may cause a greater force change. This mode is only applicable to special welding equipment with larger stiffness. Constant force control mode can ensure force stably in welding process, especially for the lack of robotic rigidity, the constant force control mode can effectively solve the impact of robotic deformation on welding quality (YAVUZ, H, 2004).

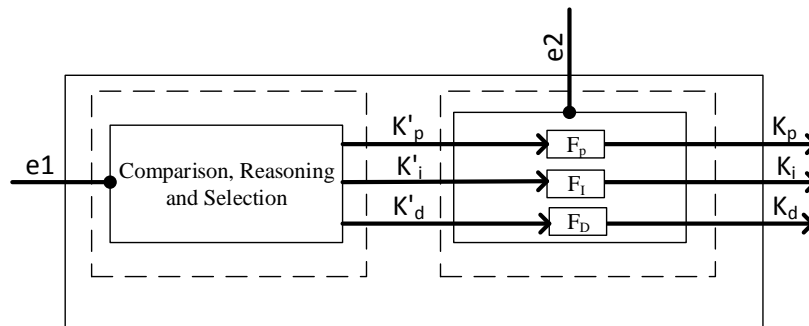


Figure 4. Adaptive control algorithm.

The two modes of constant displacement (welding depth was 4 mm) and constant force (force was 3800N) were used in FSW of 6063-T4 aluminum alloy. Weld force curves are shown in Figure 5 and Figure 6, and weld formations are shown in Figure 7 and Figure 8. For the constant displacement control, there are obvious groove on the weld surface due to

the large range of force variation, serious shaking in the plunge and poor stationarity in welding process caused by the robotic deformation. And for the constant force control, the weld performance can be improved significantly, at the same time, it has some advantages, such as stationary plunge, high precision and smooth welding process.

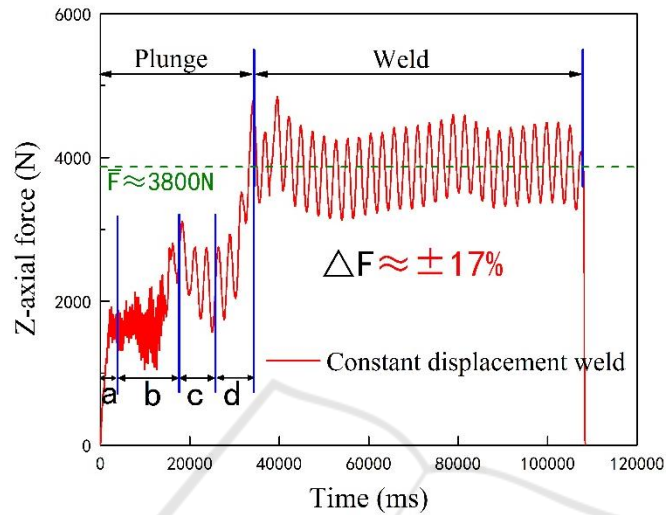


Figure 5. Curve of constant displacement.

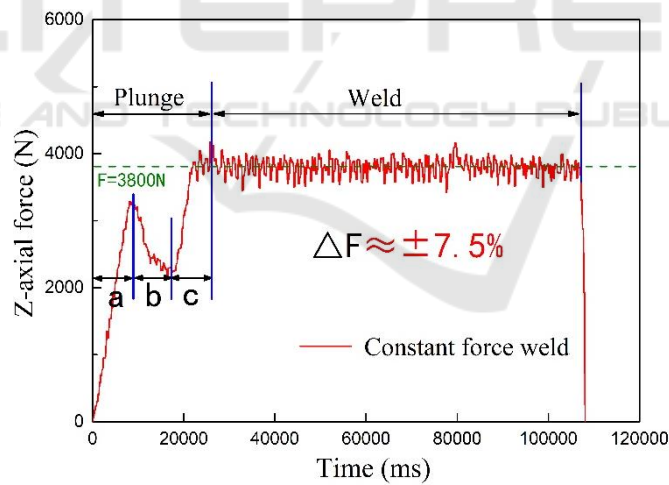


Figure 6. Curve of constant force.



Figure 7. Weld formation of constant displacement.



Figure 8. Weld formation of constant force.

5 CONCLUSION

(1) A host PC system that was suitable for robotic FSW by robotic RSI interface and C++ language was developed, and the data communication among the robotic control system, host PC system and PLC control system was realized.

(2) Considering time-delay of robot execution and technological characteristics of FSW, the redeveloped robotic program combines traditional PID control with adaptive control, controls Z-axial force can be kept constant within the range of $\pm 7.5\%$ in welding process, and enhances the welding quality significantly.

(3) The application results show that the secondary developed host PC system and program control system have characteristics of friendly operability and versatility, comprehensive data monitoring, and reduce the workload of technicians greatly.

(4) Through data monitoring, curve display, historical data calling and welding process data preservation, this research provides important methods and data support for the optimization of welding process parameters and the improvement of welding quality.

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